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The control of lead cumulation in carrot /*Daucus carota L.*/ plants by some components of the substrate

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Abstract. The effect of organic matter, phosphates, and calcium and magnesium salts in the substrate on the content of lead in carrot roots was investigated. Humus as an 8% components of soil was found most effective, decreasing Pb content in carrot by almost 2/3 in relation to plants from a mineral substrate. Phosphor (800 mg P/kg d.w.), calcium (1500 mg Ca/kg d.w.), and magnesium (240 mg Mg/kg d.w.) used as fertilizers and also an increase in pH of soil from 5.1 to 6.2 considerably limited the cumulation of lead in carrot roots

Key words: calcium, carrot, lead, magnesium, organic matter, phosphorus

Introduction

In recent decades the attention of scientists of different specialities has been directed to excessive amounts of heavy metals which appear in the natural environment owing to the rapidly developing civilization and present a wide spectrum of toxic effects to most living organisms. The subject of the most frequent and comprehensive studies is lead as practically the only metal cumulated in human organisms in amounts approximating to the clinic level (Wierzbicka, 1991).

In the ecosphere the main source of lead is the combustion of fuels and industrial emission. Lead penetrates into the soil from the atmosphere as dry (dusts) or wet (rain) deposits and, being captured by mocro-organisms and plants, enters the natural food chain. It is practically unremovable from polluted soils sonce of its total amount accumulated in the soil a neglegible part only is removed with crops of leached with rain water into deeper layers of the substrate. According to current estimates if all the sources pollution were eliminated a 10% removal of lead from the arable soil layer by means of leaching would take about 200 years and by crop uptake about 600 years (Gorlach, 1991).

In the years 1980 - 1985 Kabata-Pendias and Pendias (1993) estimated that an average annual increase in lead content in the soils of Poland amounted to 20 kg/km^2. Owing to a strong tendency to the formation of insoluble compounds with numerous organic and inorganic constituents of the substrate, a greater part of lead is fairy rapidly immobilized in these structures. Nevertheless, it may reappear in the soil solution if certain properties are changed, e.g. its mineralization and acidification occur or its sorptive capacity decreases, bringing about an increase in lead contamination of plants up to the point of an ecological disaster. Since the means of removing heavy metals from soils are not available yet, the endeavours of scientists aim at a reverse direction i.e. at binding the metals with substrates thus minimizing their activity in the root zone of plants.

The aim of the work was to investigate the effects of varied fertilization with peat, phosphorus, calcium, and magnesium in conditions of pot experiments on the cumulation of lead in carrot *(Daucus carota L.)* roots.

Material and methods

The investigation was carried out in 1990-1996 in the experimental farm of the Department of Vegetable Crops of the Cracow Agricultural University. The substrate was composed of rubbed high-moor peat and washed river sand. These two constituents were characterized by a low content of lead i.e. about 10 mg/kg d.w. in peat and about 5 mg/kg d.w. in sand, this being in accordance with the limits of the natural background of this metal in Polish soils (18 ppm, Kabata-Pendias and Pendias, 1993). The average content of organic matter in peat determined by annealing method was 95% d.w. The experiment was conducted in four substrates of a controlled composition with a varied level of one of the constituents tested:

1. The soil of a varied content of organic matter contained 0, 3, and 8% d.w. of humus. These substrates might correspond with mineral, field, and organic soils encountered in practice.
2. The soil of a varied content of phosphorus introduced to the substrate with monocalcium phosphate at the doses of 50, 200 and 800 mg P/kg d.w.
3. The soil of a varied pH value (calcium content) obtined by liming with calcium carbonate at the level of 600, 1500 and 5000 mg Ca/kg d.w. Reaction of the prepared substrates was 5.1 (acidic substrate), 6.2 (slightly acidic substrate), and 7.1 (neutral substrate).
4. The soil of a varied magnesium content of 60, 120, and 240 mg Mg/kg d.w. in the form of magnesium sulfate.

All the soils, apart from the first one, contained 8% of organic matter and, apart from the third soil, were adjusted to pH 6.5 - 6.7.

Macroelements were introduced at the level of 250 mg N, 250 mg K, 100 mg P, and 60 mg Mg/kg d.w., using pure reactive salts. The added microelements were derived from the microelement part of the multicomponent MIS-4 fertilizer.

Mitscherlich pots 5 dm^3 in volume were filled with the substrates treated with solution of lead acetate in the doses of 0, 275, and 550 mg Pb/kg d.w. This level of contamination of the experimental soils approximately corresponds to unpolluted soils,

soils from large urban agglomerations, or soils directly affected by intensive industrial emission.

The pots were placed in a hotbed, six pots being used in each experiment. Carrot seeds were sown in spring and the seedlings thinned to 8 uniform plants per pot. Carrot plants were watered with redistilled water up to the time of harvest maturity, the necessary cultural practices being carried out during that period.

Dried material was incinerated at 450°C and in the residue dissolved in a 10% nitric acid solution lead acetate was determined using atomic absorption in a Varian SpectrAA-20 spectrophotometer in an air-acetylene flame.

Before the vegetation began and after harvest of plants basic analyses of the substrates were carried out. The content of total lead was determined in soil samples burnt in an MDS-2000 microwave oven, CEM produce, in a nitric acid solution diluted 1:1

Each experiment was repeated in the following year, though two-year means were only quoted on account of an insignificant effect of the vegetation season. The results were statistically evaluated using analysis of variance in a completely randomized design and the Student t test at the significance level of 0.05.

Results

1. Carrots grown on the lead-free substrate contained 2.3 - 4.0 mg Pb/kg d.w. in roots (Fig 1). The contamination of mineral soil with lead increased the cumulation of Pb to 45.0 and 55.4 mg/kg d.w. as depending on its dose. In plants from the substrate with a 3% content of organic matter the percentage of lead was reduced to 45.9 and 45.2% (for the lower and higher Pb dose, respectively) and from the substrate with a 8% content to 32.7 and 36.0% of the level recorded in roots of plants grown in sand.

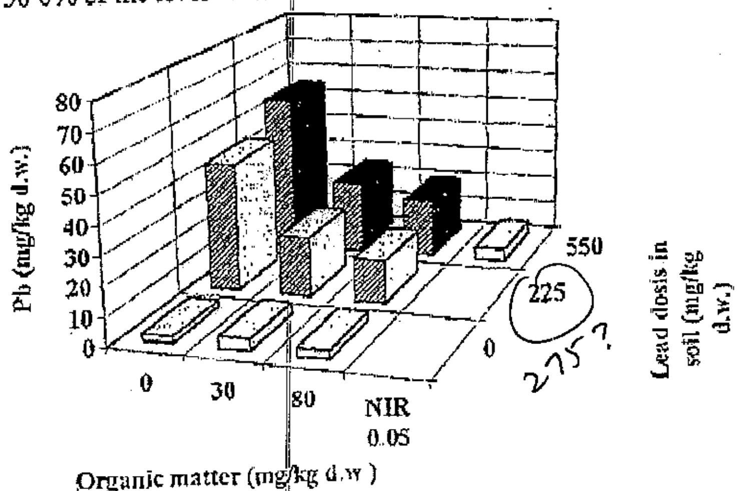

Figure 1 The control of lead cumulation in carrot plants by organic matter in the substrate

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2. Carrots assimilated lead at the level of 3.8 - 4 8 mg/kg d.w. (Fig.2). In plants from the substrate containing 50 mg Pb/kg d.w. the above value increased to 42.2 and 54.1 mg/kg d w under the influence of the succesive doses of lead. In the plant material from substrates treated with higher doses of phosphorus the content of Pb decreased to 62 1 and 76.9% and to 52.7 and 66.2% as depending on the content of the fertilizer in soil.

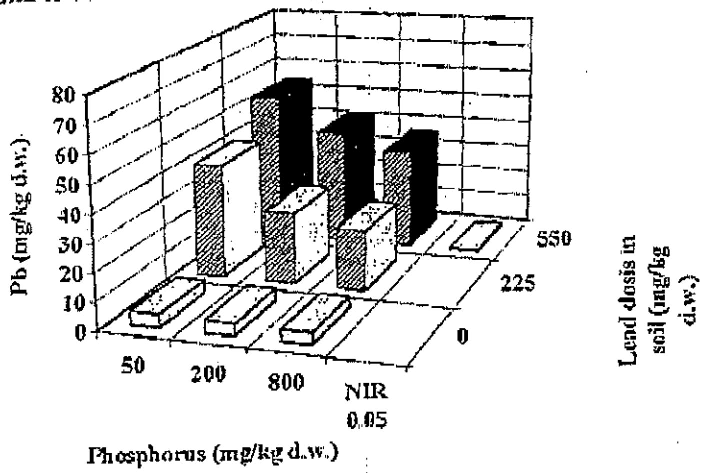

Figure 2. The control of lead cumulation in carrot plants by phosphorus in the substrate.

3. In carrots from comparative substrates the content of lead was 6 8 - 7.4 mg/kg d.w. (Fig.3). From the soil of pH 5.1 the uptake by roots was 25.7 and 32 8 mg Pb/kg d.w. as depending on the applied doses. An increase in pH to 6 2 lowered the level of lead to 75.9 and 79.9% of the above values while with a further increase in pH the expected improvement of results was not obtained.

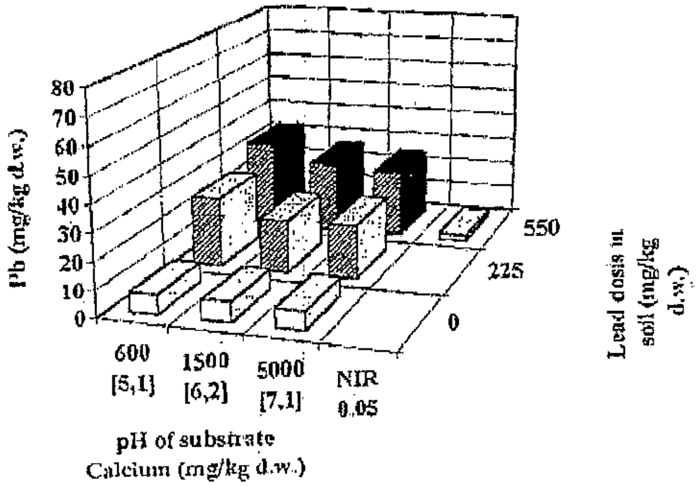

Figure 3. The control of lead cumulation in carrot plants by pH (calcium in the substrate).

4. Comparative roots of carrot contained 4.0 - 4.1 mg Pb/kg d.w. (Fig.4). In plants from the substrate with the smallest content of magnesium the effect of the lead treatment was the cumulation of 39.4 and 57.9 mg Pb/kg d.w. The effect of the increasing level of magnesium in soil was manifested by the reduction of Pb cumulation to 82.7 and 86.0% and 57.9 and 66.1% as depending on its concentration in soil and the doses of lead.

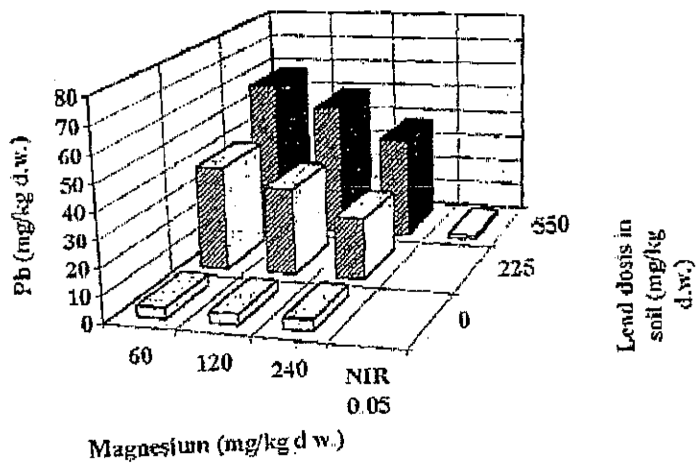

Figure 4 The control of lead cumulation in carrot plants by magnesium in the substrate.

Discussion

Owing to the tendency of lead to form hardly soluble compounds with numerous soil constituents its concentration in the soil solution is poor (from 0.1 to 10.0 $\mu g/dm^3$), being therefore regarded as a fairly immobile element. Apart from its total content, the uptake of this metal from soil by plants depends upon different relations between its forms and the organic and inorganic components of the substrate and also physico-chemical conditions in the soil complex. Studies on the status of lead in the substrate and on the conditions and mechanisms of its migration permitted various attempts at the reduction of its comulation in plants by feasible cultural practices.

The results of the discussed experiments showed that organic matter as the components of the substrate most efficiently limited the cumulation of lead. It is striking that the content of this metal in roots was reduced by about 1/2 and 2/3 as depending on the level of humus in soil in relation to the plant material obtained from mineral substrates. In numerous studies high-moor (Gawęda, 1993) and low-moor peat (Brej, Fabiszwski, 1981), manure soil, compost, dry leaves (Bassuk, 1986), straw, sawdust, tree bark, different kind of sewage sludge (Williams et al., 1984), and municipal (Sauerbeck, 1991) and industrial composts (Turski et al., 1980) were used as sources of organic matter. The obtained effects considerably differed as depending upon the source of humus, its composition and pH, and in the case of sewage sediments and composts, upon the load of heavy metals bound in them. Nevertheless, the results show that with the sufficiently high level of organic matter in the substrate the amounts of immobilized lead may reach a few hundred mg/kg d.w. Such an efficient action was shown by Liebhardt and Koske (1974) who introduced 50% of compost to the substrate containing 300 ppm Pb, and did not observe any significant increase in lead by plants.

Phosphorus treatment of soil also contributed to a pronounced control of lead uptake by carrot. The effects of phosphorus were poorer than these of organic matter and the obtained reduction approximated to 50% in the most favourable case. On the other hand it should be stressed that the application of phosphates cannot exceed the limits of ecological safety, since their excessive doses may bring about disturbances in the assimilation of other mineral constituents. The action of phosphorus fertilizers in a great measure depends upon the applied form of phosphate salt, its pH and dose. In the present study disodium orthophosphate Na_2HPO_4 (Rabinowitz, 1993), monocalcium orthophosphate $Ca/H_2PO_4/_2$ (Zimdahl, Foster, 1976), dicalcium orthophosphate $CaHPO_4$ (Judel, Stelte, 1977), monopotassium orthophosphate KH_2PO_4 (Gorlach, Gambuś, 1992), or monoammonium orthophosphate $NH_4H_2PO_4$ (Davenport, Peryea, 1991) were used, the obtained results varying to a great degree. The best effects were recorded using calcium salts, probably owing to the additional positive action of calcium. Another significant aspect of the protective role of phosphorus may be stressed. This element positively influences the condition and the resistance of plants and limits the migration of lead to plant tops (Gawęda, 1996), precipitating it in the form of orthophosphates in cell walls (Wierzbicka, 1986).

An increase in pH of soil from 5.1 to 6.2 with a simultaneous increase in calcium content reduced the lead uptake in carrot roots by about 1/4 of the initial level. Apart from the most frequently used calcium carbonate (chalk) (Sapek, 1991)also calcium oxide (quicklime) (Truby, Raba, 1991) or calcium hydroxide (slaked lime) (Harter, 1983) have been applied in this type of experiments. As the most favourable results a decrease of almost 30% in the content of lead in plant tissues was obtained, the result depending upon the kind of soil and the range of pH variation. One should also stress that in the case of the two latter compounds characterized by strong alkaline properties an increase in reaction of the substrate is rapidly obtained with lower concentrations while the effects of calcium carbonate are poorer but persist for a longer time.

In the most favourable case the fertilization with magnesium sulfate effected a reduction of lead content in carrot by about 2/5 in relation to control plants. This result shows that magnesium in the substrate also efficiently inhibits lead uptake by plants. Magnesium certainly plays as effective a role in soil as calcium yet it cannot be competitive for calcium on account of the costs and also of operative norms limiting its use. Nevertheless it may be applied as a complementary factor. Kabata-Pendias (1979) reached a similar conclusion in analysing the results of experiments with magnesium carbonate.

The present results also show that organic matter, phosphates, and calcium and magnesium salts as components of the substrate strongly promote the removal of lead from the environment of carrot roots. It is interesting that agrotechnical recommendations which might be proposed in this respect, basically agree with general principles of maintaining proper structure and fertility of soil. The binding of the greatest part of lead in soil structures is an important achievement yet in longer periods with the changing dynamic balance between their components, it may prove illusory. The investigation concerning the migration of heavy metals suggest that only a significant reduction of their inflow to the soil may solve the problem of contamination of crops with these toxins.

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Conclusions

1. Organic matter was the factor most efficiently limiting lead uptake by carrot roots. Plants grown in soil with an 8% content of humus cumulated 2/3 less than roots from a mineral substrate.
2. In conditions of the experiment fertilization with a dose of 800 mg P/kg d.w. in the form of monocalcium phosphate decreased the level Pb in carrot by about 1/2 as compared with control plants.
3. The adjustment of pH of the substrate from 5.1 to 6.2 reduced the cumulation of lead in roots by about 1/4 of the initial value.
4. High contents of calcium (1500 mg/kg d.w.) and magnesium (240 mg/kg d.w.) in the soil significantly reduced lead uptake by carrot.

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